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ORIGINAL PAPER

Fragmentation patterns and systematic transitions of the forested landscape in the upper Amazon region, Ecuador 1990–2008

Santiago Bonilla-Bedoya • Juan R. Molina • José E. Macedo-Pezzopane
Miguel A. Herrera-Machuca

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Abstract: The analysis of the systematic transitions in the forested landscape and the study of the forest fragmentation patterns allow us to deepen our understanding of the changes in the vegetation ground cover. The importance of knowing the intricate patterns of the land usage of the upper basin of the Amazon region is widely recognized. This zone is one of the most diverse biological areas in the world, is home to large areas of mature tropical cloud forest and demonstrates high probabilities of stable climatic conditions in light of global warming. The research quantified systematic transitions through the "loss" and "gain" of the different categories of landscape during the eighteen-year study period of the Ecuadorian Amazon Region (EAR), the forest fragmentation patterns were also analyzed based on a set of indicators. Therefore, with respect to the entirety of the landscape, the results registered for the ground coverage in forested areas during the first period (1990–2000), show a decrease of 6.99% and an increase of 0.68%; and during the second period (2000–2008), show a decrease of 3.99% and an increase of 2.14%. It demonstrated that forest and agricultural areas tended to replace or be replaced by herbaceous vegetation faster than expected fortuitously. Finally, the indices of fragmentation signaled intense changes during the 1990–2000 period with a reduction during the period 2000–2008. Percentages registered in the Largest Patch Index (LPI) were between 79.58%; 52.39% and 49.99% respectively; while the Patch Density (PD) varied between 0.04; 0.06 and 0.07. This suggests the propensity of forest cover to remain intact. The results of this investigation suggest a tendency towards stability in Ecuador's Amazon landscape. Within the framework for development and management of this area, the tendency is natural regeneration. This permits a consolidation of the conservation, reforestation, forestation and agricultural forestry plans, programs and systems for the protected areas in EAR.

Keywords: Ecuadorian Amazon, systematic transitions, fragmentation, natural regeneration

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Santiago Bonilla-Bedoya (✉) [1,2], Juan R. Molina [1], Miguel A Herrera-Machuca[1]
[1]Departamento de Ingeniería Forestal, E.T.S.I.A.M., Universidad de Córdoba, Campus de Excelencia Internacional Agroalimentario (ceiA3), ES-14071 Córdoba, Spain; [2]Secretaria Nacional de Educación Superior, Ciencia, Tecnología e Innovación del Ecuador, Whymper E7-37 y Alpallana Quito. Ecuador. Tel. ++34 957 212210
E-mail:santiagobonillab@hotmail.es; mherrera@uco.es

José E. Macedo-Pezzopane
Departamento de Engenharia Florestal Universidade Federal do Espírito Santo, Alegre-ES. Brazil. Pezzopane2007@yahoo.com.br

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Introduction

Although it is true that human beings have inhabited the Amazon Basin for millions of years and their presence has been a modifying agent in the landscape (Balee and Erickson 2006; Denevan 2003). In the most recent decades the expansion of the agricultural, forestry and industrial areas has had a dramatic influence on the configuration of the amazonian landscape. The study of patterns and processes related to change in the forest landscape including; the relationship between forest fragmentation, human impact, national systems for protected areas and conservation of the biodiversity, is fundamental for the management of tropical forests (Ranta et al. 1998; Revilla et al. 2001; Laurance et al. 2002; Ferraz et al. 2003; Pattanavibool et al. 2004; Guirado et al., 2006). Forest fragmentation and the deterioration of the habitat are the major causes for the loss of biodiversity and the collapse of the primary productivity in the tropical forest (Ranta et al., 1998; Laurance et al. 1997; Debinski y Holt 2000; DeFries et al., 2005; Li et al. 2009).

Forest fragmentation is defined by the reduction of the habitat nucleus and an increase in the longitude of the perimeter and border area, consequentially producing an increase in the degree of sunstroke in forest fragments (Laurance et al. 2002; Cayuela

et al. 2006). Consequently, the physical conditions and biotic of the habitat can be severely modified. This affects the patterns and distribution of species and can cause loss of species (Linera et al. 1998; Laurance et al. 1998; Cox et al. 2003).

The changes produced in the vegetation ground coverage and the development of sustainable management strategies are a research priority due to their high level of impact on climate, biochemical cycles, hydrology and biodiversity (Turner et al. 1993; Schulz et al. 2010).

Nine countries converge on the seven million km2 that envelop the Amazon basin: Brazil, Peru, Bolivia, Colombia, Ecuador, Venezuela, Guiana, Surinam and French Guiana. Currently, the Amazon basin has the highest levels of deforestation in the world and over the last fifty years, this reality has been related primarily to large-scale agriculture, industrial agriculture, the proliferation of highways and the more recent exploitation of the non-renewable natural resources, petroleum and gas (Laurance et al. 2002; Hugh et al. 2004; Michalski et al. 2010).

Scientific research related to fragmented habitats has concentrated the world's attention around the central and eastern Amazon of Brazil (Laurence et al. 2010). This research (Gardner et al., 2009; Laurance et al. 2010; Peres et al. 2010) has demonstrated that the rapid loss of forest cover and the fragmentation of mature forests is a major threat to the conservation of tropical biodiversity (Lovejoy et al., 1986; Sodhi et al., 2004; Laurance and Peres, 2006).

In contrast, the research related to habitat fragmentation is relatively new in the western and high Amazon regions including; Bolivia (Steininger et al. 2000), Peru (Oliverira et al. 2007), Colombia (Armenteras et al. 2006), Ecuador and Venezuela, where the eastern Andean Slope begins. This zone is recognized as one of the most diverse areas of the planet, and maintains large areas of mature tropical cloud forest. It also shows high probabilities for stable climatic conditions in light of global warming (Killeen et al. 2007; Finer et al. 2008).

Ecuador is one of the seventeen mega-diverse countries in the world, and houses between 5% and 10% of the planet's biodiversity, even though its territory represents less than 0.2% of the world's land surface (Albornoz et al. 2008). The diversity of the Ecuadorian Amazon Region has been documented in taxonomical studies of vegetation (Ter Steege et al. 2003), insects (Erwin et al., 2004), birds (Stotz et al. 1996) amphibians (Young et al. 2004), and mammals (Ceballos and Ehrlich 2006). Valencia et al., (2004) who found 1,114 morph-species in 62 acres of the EAR reported one significant example.

The human population is equally diverse. According to the National Institute of Statistics and Censuses (NISC) in 2010, 739,814 people lived in the Amazon territory. That is 4.9% of the total population of Ecuador. Eight indigenous nationalities are included in this percentage: Shuar, Quichua, Achuar, Huaorani, Siona, Secoya, Cofan and Zaparas. There are also zones inhabited by isolated indigenous people.

Various authors (Pinchon 1997; Acosta 2001; Fontaine 2006) have described the social- economic reasons for the change in usage of the EAR's land. In the last five decades, the primary problems encountered in the Ecuadorian Amazon are related to two activities; the extraction of non-renewable resources (petroleum); and the opening of large hubs of human activity and migratory paths promoted by the state in the 1970's. Likewise, in the last five years, studies that promote new transportation routes and extraction projects related to mining hydrocarbon in the south of the region have not been implemented. In Ecuador, the reference process for land-usage information had not been updated and only addressed work-related research development until the end of the 1990's. This impeded decision-making related to the movement of forestry resources (International Tropical Timber Association, 2001). For this reason, the State of Ecuador began a process in 2007 to generate and diffuse new information related to the movement of resources in forestry to aid in decision-making. Thus, a methodical protocol was developed (Peralvo and Delgado 2010) that established a multi-period analysis between 1990–2000 and 2000–2008.

The preliminary data from the research presented indicates a loss of forest during the 1990–2000 period of 74,330.9 ha per year, while in the 2000–2008 period; the loss was 61,764.70 ha per year. According to this data, in 2008 the rate of deforestation was 0.63% for 70% of the Continental Ecuador, which represents a change in category from "forested" to "deforested" (IPCC classification) at 61,764 ha per year. The Amazon was the region with the highest loss, approximately twenty thousand ha per year (Ecuadorian Department of Environment 2011). The current study analyzes the change process through systematic transitions between usage categories and the fragmentation patterns in the EAR during 1990–2000 and 2000–2008. Our goal was to understand the change tendencies in land usage to contribute relevant information for establishing environmental policies that facilitate decision-making for the development of forestation and reforestation programs and to see increased movement in the national system for protected areas in the Ecuadorian Amazon.

Materials and methods

An analysis of the systematic transitions (Pontius et al. 2004) of land usage in Ecuador has been realized in accordance with the study and protocol methods previously mentioned (Peralvo y Delgado 2010) for the change of land usage in Ecuador. The fragmentation patterns have been analyzed according to various requirements in the EAR.

Study Area

The EAR is defined as a biogeographic region that corresponds to territories located 1,300 m above or below sea level in the occidental foothills of the Ecuadorian Andes. It includes all of the mountain ranges and low lands to the east of said limit, and the borderlines of Colombia and Peru. It can be subdivided into two geographic sub regions: High Amazon and the Amazon Plain. It is approximately 116,644 km^2 (Fig. 1).

Regionally, the EAR has a uniform climate, highly thermal and humid. The median temperature is close to 25°C and the pluviometric levels are higher than 3000 mm annually and can

reach up to 6000 mm. Rain distribution is regular throughout the year (Pitman et al. 2001). The lands are leachate and poor (Sourdat 1986; Korning et al. 1994); nevertheless, they are relatively fertile compared with other areas of the Amazon Basin due to their sustenance in the Quarternary-Myocene epoch. The sediment that makes up the Andes has relatively enriched the land (Hoorn 2010). In any case, the chemical limitations of the land become visible in the high levels of acidity, high concentration of Al^{+3}, extremely acidic pH, low levels of P available in N, low levels of available changing bases and low quality organic material in the soil.

Seven sub-basins of the Southwestern Amazon crisscross the EAR and drain into the Amazon River. The hydrographic distribution in Ecuador's Amazon Slope is 290 billion m^3 per year, with a probable error of 10% (Albornoz et al. 2008).

The Tropical Cloud Forest dominates the major part of the landscape and is accompanied by rain forest in the flood plains and smaller wetlands. According to the suggested vegetation classification hierarchy of Ecuador (Sierra et al. 1999) these have been identified as: low-land evergreen forests, low-land black water palm forests, low-land white water rain forests, evergreen forests of the Amazon foothills, evergreen forests of the low mountains, evergreen forests of the mountain range, moorlands, high moorlands, and herbaceous low-lands.

The area protected in the Amazon is 26,791.15 km^2, which is relatively large considering the total natural protected area in the Continental Ecuador is 48,971.08 km^2 (Fig. 1).

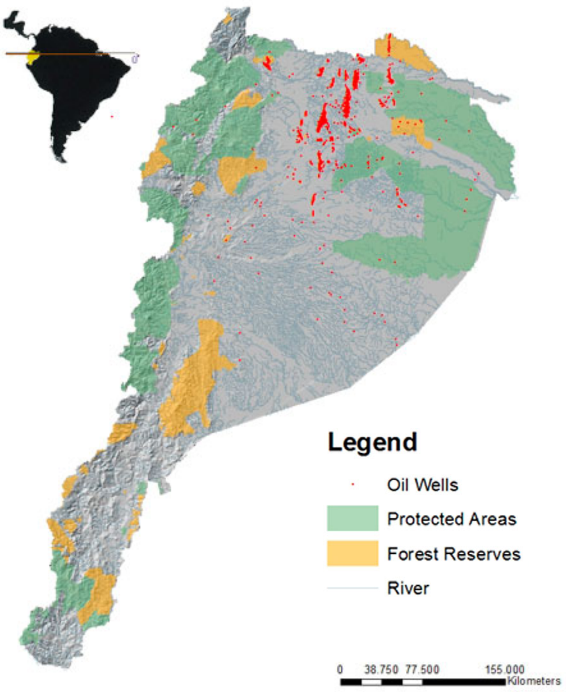

Fig 1: Study area. Ecuadorian Amazon Region (EAR). Protected Areas in green, Forest Reserves in Orange, Rivers in blue line, Red dots oil wells.

The study of the landscape included the six provinces of the EAR (Sucumbios, Orellana, Napo, Pastaza, Zamora Chinchipe, Morona Santiago), which includes: 42 counties, 43 urban districts and 165 rural districts.

The data used in this research was derived from a database produced by the Ecuadorian State, through the National System for Information. The land usage data 1990-2000-2008 and its respective usage categories have been generated by the Ecuadorian Department of Environment in conjunction with the Methodological Protocol for the Ecuadorian Deforestation Map (Peralvo and Delgado, 2010), which has considered the recommendations of the Inter-governmental Climate Change Panel (IPCC, 2006). Thus, the following basic categories of coverage were determined: (1) Agriculture, (2) Forest, (3) Wetland, (4) Herbaceous Vegetation and Moorland (5) Urban Zone and (6) Other. The database references can be found in the political administration (NISC).

Analysis of the change in ground coverage

To calculate the extension in each category the following classified maps were analyzed; ArcGIS 9.2 (ESRI, 2006) and the extension SpatialAnalyst. Cross tabulation was used between classifications through GeographicResourcesAnalysisSupportSystem (GRASS GIS), as were r.cross and r.repor. The total, gain, loss and permanence were also calculated according to the method proposed by Pontius et al. (2004). The cross tabulation analysis of change is a statistical method used to identify signs of systematic processes among different land patterns. The systematic transitions between the classifications were calculated and examined through the database matrix entries and deletions by cross tabulation and on a diagonal.

The analysis of the landscape fragmentation patterns was developed with the use of FRAGSTAT Version 3.3, and considered: (1) Patch Number (NP), (2) Patch Density (PD), (3) Mean patch area (AREA_MN), (4) Largest Patch Index (LPI), (5) Euclidean Nearest Neighbor Distance Distribution (ENN_MN), (6) Total Core Area (TCA), and (7) Core Area Percentage of Landscape (CPLAN).

Results

Changes in the land usage and systematic transitions

The total gain, total loss, total change, interchange and absolute value of net change in the landscape for each category during the 1990–2000 and 2000–2008 periods are demonstrated in Table 1. Here, the "Forest" category shows the highest loss during the two periods, while the most important gains were found in the "Agriculture" category. Another important relation was observed in the gains and losses of the "Herbaceous Vegetation and Moorland" category, which, after "Forest" and "Agriculture" accounts for the largest extension in the Amazon landscape.

Finally, during the two periods, the total change of the landscape was highest in the "Forest" and "Agriculture" categories.

Table 1: Changes in the land usage in the Ecuador Amazon Region (%), periods 1990–2000, 2000–2008

Period	Category	Gain	Loss	Total Change	Interchange	Absolute value of net change
1990–2000	Agriculture	5.32	0.40	5.72	0.8	4.92
	Forest	0.68	6.09	6.77	1.36	5.41
	Urban Zone	1.18	0.07	1.25	0.13	1.12
	Other	0.06	0.14	0.2	0.12	0.08
	Herbaceous Vegetation and Moorland	1.36	0.83	2.19	1.66	0.53
	Wetland	0.09	1.17	1.26	0.18	1.08
2000–2008	Agriculture	3.07	2.19	5.26	4.37	0.89
	Forest	2.14	3.99	6.13	4.27	1.86
	Urban Zone	0.28	0.30	0.58	0.55	0.03
	Other	0.11	0.08	0.19	0.17	0.02
	Herbaceous Vegetation and Moorland	2.15	1.25	3.4	2.51	0.89
	Wetland	0.11	0.03	0.14	0.07	0.07

The most significant systematic transitions that occurred in both periods between categories are shown in Tables 2, 3, 4 and 5. Here, in terms of gain in the EAR (1990–2000) the "Agriculture" areas did not replace "Forest" areas, rather they replaced "Herbaceous Vegetation and Moorland", specifically when "Agriculture" areas replaced "Herbaceous Vegetation and Moorland" areas at a rate of 0.61% faster than what would have been expected in the case of random gain. The results also revealed that gain in "Forest" areas was related with the "Herbaceous Vegetation and Moorland" areas, which were replaced by "Forest" at a rate of 0.9% faster than expected. In addition, when gain occurred in the "Herbaceous Vegetation and Moorland" areas, it was not replaced by "Forest"; rather, it replaced "Agriculture" areas 1.5% more than expected if "Herbaceous Vegetation and Moorland" areas had experienced random gain.

Also, when the categories gained, they tended to replace "Herbaceous Vegetation and Moorland" by (0.69%). Nevertheless, they were reluctant to replace the "Forest" and "Agriculture" categories outside of the expected random processes (Table 2). In this context, "Herbaceous Vegetation and Moorland" experienced a loss while "Agriculture" and "Forest" areas tended to remain in place.

Table 2: Systematic transitions in the gain function. Ecuador Amazon Region, 1990–2000

Transition	Observed minus expected*	Difference divided by expected	Interpretation of systematic transition
Forest in 1990 and Agriculture in 2000	-0.13	-0.03	When Agriculture gains, it does not replace Forest
Herbaceous Vegetation and Moorland in1990 and Agriculture in 2000	0.13	0.61	When Agriculture gains, it replace Agriculture gains
Agriculture in 1990 and Forest in 2000	-0.23	-0.58	When forest gains, it does not replace Agriculture.
Herbaceous Vegetation and Moorland in 1990 and Forest in 2000	0.21	0.90	When forest gains, it replaces Herbaceous Vegetation and Moorland.
Agriculture in 1990 and Herbaceous Vegetation and Moorland in 2000	0.13	1.50	When Herbaceous Vegetation and Moorland gains, it replaces Agriculture.
Forest in 1990 and Herbaceous Vegetation and Moorland in 2000	-0.22	-0.18	When Herbaceous Vegetation and Moorland gains, it does not replace Forest.
Forest in 1990 and non- Forest in 2000	-1.46	-0.19	When non-forest categories gain, they no not replace Forest. Forest does not lose.
Agriculture in 1990, non- Agriculture in 2000	-0.17	-0.30	When non-Agriculture categories gain, they no not replace Agriculture. Agriculture does not lose.
Herbaceous Vegetation and Moorland in 1990 and non-Herbaceous Vegetation and Moorland 2000.	0.34	0.69	When non-Herbaceous Vegetation and Moorland categories gain, they replace Herbaceous Vegetation and Moorland. Herbaceous Vegetation and Moorland loses.

* If the gain in the categories had been given randomly, differences should be zero, however many of the differences aren't close to zero.

The most important systematic transitions in light of the losses in the EAR, during 1990-2000 manifested that when "Forest" lost, it was replaced by "Agriculture" more than by "Herbaceous Vegetation and Moorland" (Table 3). "Herbaceous Vegetation and Moorland" was replaced by "Forest" more than by "Agriculture" areas. The loss of "Agriculture" areas maintained its correlation with "Herbaceous Vegetation and Moorland". It is because of this that when the categories experience a loss they tend to be replaced by either "Forest" or "Herbaceous Vegetation and Moorland", and not by "Agriculture" areas.

In regards to the 2000–2008 period; because of the gains transition, the dynamic of the prior decade continued (Table 4). The "Agriculture" category did not replace "Forest" but it did replace "Herbaceous Vegetation and Moorland" at a rate of 1.50% faster than if "Agriculture" areas had experienced random gain. When the "Forest" category experienced gain, it tended to systematically gain "Herbaceous Vegetation and Moorland" (0.61%); thus, the "Forest" category did not tend to systematically gain "Agriculture" areas. Also related to the gaining of "Herbaceous Vegetation and Moorland", was the tendency to replace "Agriculture" areas at a rate of 2.58% faster than expected fortuitously.

Finally, when the categories experienced gain they tended to replace "Agriculture" and "Herbaceous Vegetation and Moorland" areas; although reluctant to replace "Forest". Hence, "Agriculture" areas and "Herbaceous Vegetation and Moorland" experienced loss while the "Forest" category tended to remain constant.

Table 3: Systematic transitions in the loss function. Ecuador Amazon Region, 1990-2000.

Transition	Observed minus expected	Difference divided by expected	Interpretation of systematic transition
Forest in 1990 and Agriculture in 2000	0.66	0.15	When Forest loses, Agriculture replaces it.
Herbaceous Vegetation and Moorland in 1990 and Agriculture in 2000	-0.56	-0.35	When Forest loses, Herbaceous Vegetation and Moorland does not replace it.
Agriculture in 1990 and Forest in 2000	-0.24	-2.42	When Herbaceous Vegetation and Moorland loses, Agriculture does not replace it.
Herbaceous Vegetation and Moorland in 1990 and Forest in 2000	0.28	0.38	When Herbaceous Vegetation and Moorland loses, Forest replaces it.
Agriculture in 1990 and Herbaceous Vegetation and Moorland in 2000	0.20	10.58	When Agriculture loses, Vegetation and Moorland loses replaces it.
Forest in 1990 and Herbaceous Vegetation and Moorland in 2000	-0.21	-0.55	When Agriculture loses, Forest does not replace.
Forest in 1990 and non- Forest in 2000	1.59	0.70	When non-Forest categories loses. Forest replaces them. Forest gain.
Agriculture in 1990, non- Agriculture in 2000	-0.78	-0.17	When non-Agriculture categories lose, Agriculture does not replace. Agriculture does not gain.
Herbaceous Vegetation and Moorland in 1990 and non- Herbaceous Vegetation and Moorland 2000.	0.32	0.19	When non-Herbaceous Vegetation and Moorland loses, Herbaceous Vegetation and Moorland replace them. Herbaceous Vegetation and Moorland gains.

* If the gain in the categories had been given randomly, differences should be zero, however many of the differences aren't close to zero.

Table 4: Systematic transitions in the gain function. Ecuador Amazon Region, 2000-2008.

Transition	Observed minus expected*	Difference divided by expected	Interpretation of systematic transition
Forest in 2000 and Agriculture in 2008	-0.27	-0.09	When Agriculture gains, it does not replace Forest.
Herbaceous Vegetation and Moorland in 2000 and Agriculture in 2008	0.20	1.50	When Agriculture gains, it replace Herbaceous Vegetation and Moorland
Agriculture in 2000 and Forest in 2008	0.32	0,61	When Forest gain, it replace Herbaceous Vegetation and Moorland.
Herbaceous Vegetation and Moorland in 2000 and Forest in 2008	-0.42	-0.27	When Forest gain, it does not replace Agriculture.
Agriculture in 2000 and Herbaceous Vegetation and Moorland in 2008	-0.73	-0.39	When Herbaceous Vegetation and Moorland gain, it does not replace Forest.
Forest in 2000 and Herbaceous Vegetation and Moorland in 2008	0.65	2.58	When Herbaceous Vegetation and Moorland gains, it replaces Agriculture.
Forest in 2000 and non- Forest in 2008	-1.23	-0.23	When non-Forest categories gain, they no not replace Forest. Forest does not lose.
Agriculture in 2000, non- Agriculture in 2008	0.33	0.18	When non-Agriculture categories gain, They no not replace Agriculture. Agriculture does not lose.
Herbaceous Vegetation and Moorland in 2000 and non- Herbaceous Vegetation and Moorland 2008.	0.60	0.91	When non-Herbaceous Vegetation and Moorland gain, they replace Herbaceous Vegetation and Moorland. Herbaceous Vegetation and Moorland lose.

* If the gain in the categories had been given randomly, differences should be zero, however many of the differences aren't close to zero.

The transitions related to loss in the 2000–2008 period are presented in Table 5. Here, the loss in "Forest" and "Agriculture" areas was substituted by the "Herbaceous Vegetation and Moorland" category; while this particular category continued to be replaced by "Agriculture" areas. Therefore, when the categories experienced loss, they tended to be replaced by "Forest" (0.39%)

and “Herbaceous Vegetation and Moorland” (0.77%), in light of the expected random process.

Table 5: Systematic transitions in the loss function. Ecuador Amazon Region, 2000–2008

Transition	Observed minus expected*	Difference divided by expected	Interpretation of systematic transition
Forest in 2000 and Agriculture in 2008	-0.13	-0.05	When Forest loses, Agriculture does not replace it.
Herbaceous Vegetation and Moorland in 2000 and Agriculture in 2008	0.08	0.07	When Forest loses, Herbaceous Vegetation and Moorland replace it.
Agriculture in 2000 and Forest in 2008	-0.92	-0.45	When Agriculture loses, Forest does not replace it.
Herbaceous Vegetation and Moorland in 2000 and Forest in 2008	0.79	6.71	When Agriculture loses, Herbaceous Vegetation and Moorland replace it.
Agriculture in 2000 and Herbaceous Vegetation and Moorland in 2008	-0.24	-0.22	When Herbaceous Vegetation and Moorland loses, Forest does not replace it.
Forest in 2000 and Herbaceous Vegetation and Moorland in 2008	0.17	1.06	When Herbaceous Vegetation and Moorland lose, Agriculture replaces it.
Forest in 2000 and non- Forest in 2008	1.34	0.39	When non-Forest categories lose, Forest replaces them. Forest gain.
Agriculture in 2000, non- Agriculture in 2008	-0.07	-0.02	When non-Agriculture categories lose, Agriculture does not replace. Agriculture does not gain.
Herbaceous Vegetation and Moorland in 2000 and non- Herbaceous Vegetation and Moorland 2008.	0.93	0.77	When non-Herbaceous Vegetation and Moorland categories lose, Herbaceous Vegetation and Moorland replace them. Herbaceous Vegetation and Moorland gain.

* If the gain in the categories had been given randomly, differences should be zero, however many of the differences aren’t close to zero.

Forest fragmentation

“Forest” is the dominating landscape in the EAR even though in the last eighteen years the changes (Table 6) have been significant. The LPI reduced, indicating an underestimation of the “Forest” category, which reduced by 27.19% in the 1990–2000 period and 2.39% in the 2000–2008 period (Fig. 2).

Table 6: Fragmentation Index for the Ecuadorian Amazon region in the periods 1990, 2000 and 2008

Index	1990	2000	2008
LPI	79.59	52.39	50.00
PD	0.04	0.06	0.07
NP	4,147	6,149	6,581
AREA_MN	2,035.70	1,285.69	1,173.18
TCA	5145,128.00	4544,204.00	4361,612.00
CPLAN	54.14	47,93	46.17
ENN-MN	509,74	504.37	513.43

The tendency to dominate was inverted in the case of NP and PD. Thus, 2,002 new fragments appeared between 1990 and 2000 and 432 fragments integrated into the Amazon landscape between 2000 and 2008. Likewise, the PD increased from 0.04 to 0.06 fragments per area unit between the two periods.

The AREA_MN, registered losses of 2,035.7 ha compared to 1,285.7 ha in the last eighteen years; that is to say, a reduction of 36.84% over a ten-year period.

In addition to the reduction of “Forest” was the isolation of the fragments therein, even though the average distance between fragments did not show substantial differences in the three parts of the sequence. In 2008, larger differences were registered in the average distances between fragments (509.74 m; 504.37 m; 513.43 m). Finally, the TCA (border of 500 m), in the “Forest” category tended to diminish as time passed, just as the percentage of the nucleus area did in regards to the landscape.

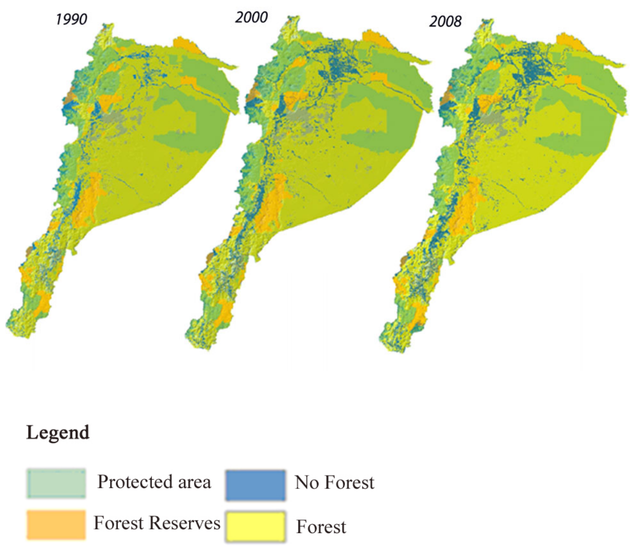

Fig. 2: Landscape fragmentation in the Amazon region of Ecuador (1990, 2000 and 2008). Between 1990–2000 the fragmentation processes are higher in the second stage (2000–2008) there is a tendency to stability. The "forest" in olive green, blue non-forest category. Protected areas in green and orange forest reserve

Discussion

The results presented in this research provide information about the changes in land usage, the systematic transitions and the patterns of fragmentation in the Ecuadorian Amazon. Following the methodology applied (Pontius et al, 2004), the relationships produced between the different categories have been shown in detail. In the first period of the sequence, the categories showed more intense change in comparison with the second period. Especially highlighted was the loss in the "Forest" category and the gain in "Agriculture" areas during the first part of the sequence. Afterwards, during the second period, a proportional pattern was seen between the loss and gain, suggesting stability. More recent trends suggest that the land surface for cultivation has stabilized in Latin America (Verchot, 2010).

The reduction in the fragmentation patterns is related to the migratory flow experienced in the EAR. Immigration during the 1970's was possibly responsible for the landscape changes in the 1980's and 1990's, principally due to the vitality and growth of the petroleum, agricultural and forest industries. The diminishing intensity in the change rate responds to emigration and abandonment of lands. Pinchon (1997) and Fontaine (2006) maintain that many rural workers and settlers lost or abandoned their land in the EAR due to low productivity levels and thus lacked assurance of their subsistence. Similar migration and abandonment has been reported in other Amazonian countries due to poor soil quality and low productivity levels (Mesquita et al. 1999). However, there are other contradicting cases, for example; Colombia has reported intense changes in land usage due to the growing rural population over the last decade (Armenteras et al. 2006).

In relation to the transformation in the categories experiencing larger expansion, ("Forest", "Agriculture", "Herbaceous Vegetation and Moorland"), the results indicate a confirmation of the importance of factors such as: natural regeneration, recuperation of individual remnants, germination from the wealth of seed in the soil, shoots from cut roots or ground flesh, dispersion of seed, migration from other areas and the fertility of the soil (Tucker et al., 1997; Moran et al., 2000). This may further the restoration of the tropical forest. With that, the research and management for this type of effects would be one step closer to inclusion in programs that further bio-diverse restoration, ecological functioning and the supply of eco-systemic goods and services previously used for the native communities in the EAR. This idea is corroborated by Lamb et al. (2005), who protects and administrates large areas of secondary and regrowing forest as a measure to increase the forestry coverage in areas that have lost the original forest coverage.

An analysis of the results equally suggests a relatively high capacity for resilience in the "Herbaceous Vegetation and Moorland" and "Forest" categories in the Amazon landscape in Ecuador. In spite of the movement of this ground coverage, the restoration of the forest will prosper. Nevertheless, Saldarriaga et al., (1988) should be considered in reference to the recuperation of the tropical forest. Here it suggests that an uninterrupted period of 190 years is required for a previously cultivated area to show the biomass basics and values that correspond to a mature forest.

One of the indicators that show the fragmentation of the forest is the NP and AREA_MN (Li et al. 2009). In the case of the EAR, the results showed an increase in the fragmentation patterns in the "Forest" category, surpassing the estimates given by the United Nations Environmental Program (Albornoz et al. 2008). The 2001 study presented 3,502 fragments on the Continental Ecuador with an average of 39.6 km^2. These differences possibly indicate the use of different methodology in the estimation process.

In the same way, the resulting consequences should also be considered due to the edge effect that they have on the patch forest. Skole and Tucker (1993), reported a larger area of fragmented forest (<100 km^2) in the central Amazon region in Brazil due to the edge effect (<1 km), which increased more than 150% in relation with the deforested area.

Although this suggested stability, the tendency still signals a reduction in the AREA_MN, and the repercussion could be the loss of species. Smaller fragments have shown faster losses of species (Lovejoy et al. 1986; Stouffer et al. 2009). In addition, the importance of the width of the fragment should be considered in view of the richness of many-organism species (Laurance et al. 2010). Several research projects have reported a correlation between the size of the fragments and bryophyte leaves (Zartman 2003), tree seedlings (Benitez-Malvido and Martinez-Ramos, 2003), palms (Scariot, 1999), among others. The fragment size is a determining factor for these groups to sustain viable populations while also considering the abrupt, unfavorable ecological changes caused by the edge effect (Didham et al. 1998). In addition, particularly in the EAR, there are cross-factors between the deforestation hubs and the zones that have experienced illegal hunting and commercialization of species of fauna, (Suarez et al. 2009), which complicate the environment for those populations.

Conclusions

In Ecuador's high Amazon basin, during the years of 1990–2008, the "Forest" and "Agriculture areas" categories replaced or were replaced more rapidly than would be expected in random process by "Herbaceous Vegetation and Moorland". In relationship to the fragmentation indexes during the 1990, 2000 and 2008 period, the propensity was towards permanence in the "Forest" coverage, which demonstrates a tendency towards stability in the Amazon landscape of Ecuador, previously characterized as in the process of petroleum extraction and colonization.

In a world where the production and consumption of forest resources is increasingly fulfilling its demand in tropical countries, I urge the development of sustainable production methods. Under these parameters in the tropics, forest legislation cannot ignore the protection and administration of the large regrowth areas. It is one of the measures that can be taken to increase the forest cover in areas that have lost their original forest cover. With the results in mind, considering the zones that have reestablished "herbaceous vegetation" as priority zones for the development of the Amazon landscape, developing conservation, re-

forestation, forestation and agro-forestation plans and programs.

The next few years will determine the future of the EAR. The tendency towards stability could be affected by the execution of potential new projects related to the vitality and extraction of unrenewable resources. It is because of this that the new evaluation mechanisms in the reestablished zones will help continue this tendency.

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References

Acosta A. 2001. Brief Economic History of Ecuador. Ecuador.

Albornoz P. Andrade M, Araujo P, Gómez D, Mejía D, Pohlenz A, Torres F, Morales M. 2008. Geo Ecuador 2008.

Armenteras D, Rudas G., Rodriguez N, Sua S, Romero M. 2006. Patterns and causes of deforestation in the Colombian Amazon. *Ecological Indicators*, **6**: 353–368.

Balée W, Erickson C. 2006. Time, Complexity, and Historial Ecology. United State America.

Benítez MJ, Martínez RM. 2003. Impact of Forest Fragmentation on Understory Plant Species Richness in Amazonia. *Conservation Biology*, **17**: 389–400.

Cayuela L, Benayas JMR, Echeverría C. 2006. Clearance and fragmentation of tropical montane forests in the Highlands of Chiapas, Mexico (1975–2000). *Forest Ecology and Management*, **226**: 208–218.

Ceballos G., Ehrlich PR. 2006. Global mammal distributions, biodiversity hotspots, and conservation. *Proceedings of the National Academy of Sciences of the United States of America*, **103**: 19374–19379.

Cox M. 2003. Effects of rainforest fragmentation on non-flying mammals of the Eastern Dorrigo Plateau, Australia. *Biological Conservation,* **115**: 175–189.

DeFries R, Hansen A, Newton A, Hansen M, 2005. Increasing isolation of protected areas in tropical forests over the past twenty years. *Ecological Application*, **15**: 19–26.

Debinski DM, Holt RD. 2000. A Survey and Overview of Habitat Fragmentation Experiments. *Conservation Biology*, **14**: 342–355.

Denevan WM. 2003. The Native Population of Amazonia in 1492 Reconsidered. *Revista de Indias*, **LXIII**(227):. 175–187.

Didham RK. 1998. Altered leaf-litter decomposition rates in tropical forest fragments. *Oecología*, **116**: 397–406.

Erwin TL, Pimienta M, Murillo E, Aschero V. 2004. Mapping patterns of β-diversity for beetles across the western Amazon Basin: A preliminary case for improving conservation strategies. *Proc Calif Acad Sci*, **56**: 72–85.

Ferraz G., Russell G.J, Stouffer PC, Bierregaard RO, Pimm SL, Lovejoy TE. 2003. Rates of species loss from Amazonian forest fragments. *Proceedings of the National Academy of Sciences of the United States of America,* **100**: 14069–14073.

Finer M, Jenkins CN, Pimm SL, Keane B, Ross C. 2008. Oil and gas projects in the Western Amazon: threats to wilderness, biodiversity, and indigenous peoples. PloS one 3, e2932.

Fontaine G.. 2006. Globalization of the Amazon: an Andean perspective. *Íconos,* **25**: 25–36.

Gardner TA, Barlow J, Chazdon R, Ewers RM, Harvey CA, Peres CA, Sodhi NS. 2009. Prospects for tropical forest biodiversity in a human-modified world. *Ecology Letters*, **12**: 561–582.

Guirado M, Pino J, Rodà F. 2006. Understorey plant species richness and composition in metropolitan forest archipelagos: effects of forest size, adjacent land use and distance to the edge. *Global Ecology and Biogeography,* **15**(1): 50–62.

Hoorn C, Wesselingh FP, ter Steege H, Bermudez MA, Mora A, Sevink J, Sanmartín I, Sanchez-Meseguer A, Anderson CL, Figueiredo JP, Jaramillo C, Riff D, Negri FR, Hooghiemstra H, Lundberg J, Stadler T, Särkinen T, Antonelli A. 2010. Amazonia through time: Andean uplift, climate change, landscape evolution, and biodiversity. *Science*, **330**: 927–31.

Hugh DE, Belward AS, De Miranda EE, Di Bella CM, Gond V, Huber O, Jones S, Sgrenzaroli M, Fritz S. 2004. A land cover map of South America. *Global Change Biology*, **10**: 731–744.

ITTO (International Tropical Timber Organization) 2006. Ecuador. *In*: *Status of Tropical Forest Management* 2005. ITTO Technical Series 24, pp. 224–230.

Killeen TJ, Douglas M, Consiglio T, Jørgensen PM, Mejia J. 2007. Dry spots and wet spots in the Andean hotspot. *Journal of Biogeography*, **34**: 1357–1373.

Korning J, Thomsen K, Dalsgaard K. 1994. Characters of three Udults and their relevance to the composition and structure of virgin rain forest of Amazonian Ecuador. *Geoderma,* **63**(2): 145-164

Lamb D, Erskine PD, Parrotta JA. 2005. Restoration of degraded tropical forest landscapes. *Science*, **310**: 1628–32.

Laurance WF, Camargo JLC, Luizão RCC, Laurance, SG., Pimm SL, Bruna EM, Stouffer PC, Bruce Williamson G., Benítez-Malvido J, Vasconcelos HL. 2011. The fate of Amazonian forest fragments: A 32-year investigation. *Biological Conservation*, **144**: 56–67.

Laurance WF, Ferreira L, Rankin-de Merona J, Laurance SG., Hutchings R, Lovejoy TE. 1998. Effects of Forest Fragmentation on Recruitment Patterns in Amazonian Tree Communities. *Conservation Biology*, **12**(2): 460–364.

Laurance WF, Laurance SG., Ferreira L, Rankin-de Merona J, Gascon C, Lovejoy TE, 1997. Biomass collapse in Amazonian forest fragments. *Science*, **278**: 1117–1118.

Laurance WF, Lovejoy TE, Vasconcelos HL, Bruna EM, Didham RK, Stouffer PC, Gascon C, Bierregaard RO, Laurance SG., Sampaio E. 2002. Ecosystem decay of Amazonian forest fragments: a 22-Year investigation. *Conservation Biology*, 16: 605–618.

Laurance WF, Peres CA. 2006. *Emerging Threats to Tropical Forests*. United States: University of Chicago Press, p.520.

Li HM, Ma YX, Liu WJ, Liu WJ. 2009. Clearance and fragmentation of tropical rain forest in Xishuangbanna, SW, China. *Biodiversity and Conservation,* **18**: 3421–3440.

Linera GW, Domíinguez-Gastelúu V, García-Zurita ME. 1998. Microenvironment and floristics of different edges in a Fragmented Tropical Rainforest. *Conservation Biology*, **12**: 1091–1102.

Lovejoy TE, Bierregaard RO, Rylands AB, Malcolm Jr, Quintela CE, Harper LH, Brown KS, Powell AH, Schubart HO, Hays MB. 1986. Edge and other effects of isolation on Amazon forest fragments. *In*: M. E. Soulé

(ed), *Conservation biology: the science of scarcity and diversity*. Sunderland, Massachusetts: Sinauer Associates, pp.257–285

Mesquita RCG., Delamo P, Laurance WF. 1999. Efect of surrounding vegetation on edge-related tree mortality in Amazonian forest fragments. *Biological Conservation*, **91**: 129–134.

Michalski F, Metzger JP, Peres CA. 2010. Rural property size drives patterns of upland and riparian forest retention in a tropical deforestation frontier. *Global Environmental Change*, **20**: 705–712.

Moran EF, Brondizio ES, Tucker JM, Clara M, Mccracken S, Falesi I. 2000. Effects of soil fertility and land-use on Ã nia forest succession in Amazo. *Forest Ecology and Management*, **139**: 93–108.

Oliveira PJC, Asner GP, Knapp DE, Almeyda A, Galván-gildemeister R, Keene S, Raybin RF, Smith RC. 2007. Land-use allocation protects the Peruvian Amazon. *Science*, **317**: 2005–2008.

Pattanavibool A, Dearden P, Kutintara U. 2005. Habitat fragmentation in north Thailand: a case study. *Bird Conservation International*, **14**: 13–22.

Peralvo M, Jeaneth D. 2010. Methodological Protocol for the Ecuadorian Deforestation Map. Ministerio del Ambiente del Ecuador.

Peres CA, Gardner TA, Barlow J, Zuanon J, Michalski F, Lees AC, Vieira ICG, Moreira FMS, Feeley KJ. 2010. Biodiversity conservation in human-modified Amazonian forest landscapes. *Biological Conservation*, **143**: 2314–2327.

Pichón FJ. 1997. Colonist land-allocation decisions, land use, and deforestation in the Ecuadorian Amazon frontier. *Economic Development and Cultural Change*, **45**(4): 707-744

Pitman N, Terborgh J, Silman M, Núñez P, Neill D Cerón C, Palacios W, Aulestia M. 2001. Dominance and distribution of tree species in upper Amazonian terra firme forests. *Ecology,* **82**(8): 2101–2117

Pontius RG., Shusas E, McEachern M. 2004. Detecting important categorical land changes while accounting for persistence. *Agriculture, Ecosystems & Environment*, **101**: 251–268.

Ranta P, Blom TOM. 1998. The fragmented Atlantic rain forest of Brazil: size, shape and distribution of forest fragments. *Biodiversity and Conservation*, **403**: 385–403.

Revilla E, Palomares F, Delibes M. 2001. Edge-core effects and the effectiveness of traditional reserves in conservation: Eurasian badgers in Doñana National Park. *Conservation Biology*, **15**: 148–158.

Saldarriaga JG., West DC, Tharp ML. 1988. Long-term chronosequence of forest succession in the upper Rio Negro of Colombia and Venezuela. *Journal of Ecology*, **76**: 938–958.

Scariot A. 1999. Forest fragmentation effects on palm diversity in central Amazonia. *Journal of Ecology*, **87**: 66–76.

Schulz JJ, Cayuela L, Echeverria C, Salas J, Rey Benayas JM. 2010. Monitoring land cover change of the dryland forest landscape of Central Chile (1975–2008). *Applied Geography,* **30**: 436–447.

Sierra R, Campos F, Chamberlin J. 2002. Assessing biodiversity conservation priorities: ecosystem risk and representativeness in continental Ecuador. *Landscape and Urban Planning,* **59**(2): 95–110

Skole D, Tucker C. 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978-1988. *Scienc*e, **260**: 1905–1910.

Sodhi NS, Koh LP, Brook BW, Peter Ng KL. 2004. Southeast sian biodiversity: an impending disaster. *Trends in Ecology & Evolution,* **19**(12): 654–60.

Sourdat M. 1986. Les sols de l’ Amazonie équatorienne: situation, nature, perspectives d'exploitation. *Cahiers ORSTOM.Série Pédologie,* **22**(4) : 409–428.

Ter Steege H, Pitman N, Sabatier D, Castellanos H, Hout PVD, Day DC, Silveira M, Phillips O, Thomas R, Essen JV, Baider C, Maas P, Mori S, Terborgh J, Vargas Pn, Mogollon H, Morawetz W. 2003. A spatial model of tree a-diversity and tree density for the Amazon. *Biodiversity and Conservation*, **12**(11): 2255–2277.

Steininger MK, Tucker CJ, Townshend JRG, Killeen J, Desch A, Bell V, Ersts P. 2000. Tropical deforestation in the Bolivian Amazon. *Environmental Conservation,* **28**: 127–134

Stouffer PC, Strong C, Naka LN. 2009. Twenty years of understorey bird extinctions from Amazonian rain forest fragments: consistent trends and landscape-mediated dynamics. *Diversity and Distributions,* **15**: 88–97.

Stotz Df, fitzpatrick JW, Parker TE, Moskowitz DK. 1996. *Neotropical Birds, Ecology and Conservation*. University of Chicago Press, p.478.

Suárez E, Morales M, Cueva R, Utreras Bucheli V, Zapata-Ríos G, Toral E, Torres J, Prado W, Vargas Olalla J. 2009. Oil industry, wild meat trade and roads: indirect effects of oil extraction activities in a protected area in north-eastern Ecuador. *Animal Conservation,* **12**: 364–373.

Tucker NI, Murphy TM. 1997. The effects of ecological rehabilitation on vegetation recruitment: some observations from the Wet Tropics of North Queensland. *Forest Ecology and Management*, **99**: 133–152.

Turner BL, Moss RH, Skole DL.1993. Relating Land Use and Global Land-cover Change: A Proposal for an IGBP-HDP core Project. Report from the IGBP-HDP Working Group on Land-Use/Land-Cover Change (=IGBP Report 24/HDP Report 5), Stockholm: Royal Swedish Academy of Sciences.

Verchot L. 2010. Impacts of forest conversión to agriculture on microbial communities and microbial function. In: Dion, P. (ed.), *Soil Biology and Agriculture in the Tropics*. London, UK: Springer, pp. 45–63

Young BE, Stuart SN, Chanson JS, Cox NA, Boucher TM. 2004. *Disappearing Jewels: The Status of New World Amphibians*. Arlington, Virginia. NatureServe, p.53.

Zartman C. 2003. Habitat fragmentation impacts on epiphyllous bryophyte communities in Central Amazonia. *Ecology*, **84**(4): 948–954.